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(54) **Seismic signal velocity filtering.**

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Description

The present invention relates to a method of velocity filtering seismic signals, and to an installation for implementing the method.

The invention relates to studying underground formations, in particular by the so-called "Vertical Seismic Profile" technique in which a seismic wave detector is placed in a borehole successively at different depths, with seismic waves being emitted from a source on the surface and with the signals produced by the detector being recorded.

The essential purpose of these measurements is to determine the reflective horizons or reflectors which are situated deeper than the bottom of the borehole by analyzing the waves reflected on these reflectors and rising towards the detector, which waves are called "upgoing" waves.

However, the detected waves comprise not only the upgoing waves, but also waves known as "downgoing" waves which are waves that have propagated directly from the source to the detector, waves which have been subjected to multiple reflections, and interfering waves of various kinds.

By putting together all of the recorded signals in a single document, it is possible to detect coherencies between the various traces, but given the multiplicity of superposed components in each signal, such a document is extremely difficult to interpret.

In order to detect reflectors and their positions, it is therefore desirable to filter the recorded signals in order to show up the upgoing waves.

A first filter method for reinforcing a given wave component in a set of signals recorded at levels z_i (where i lies between 1 and n) is described in patent document FR-A-2 494 450. This filtering consists in advancing the m ($m < n$) first signals $g_i(t)$ recorded at levels z_i by a time t_i where $2 < i < m$ relative to the signal $g_1(t)$ at level z_1 in order to align the downgoing wave components and produce a first signal by adding together the signals shifted in this way. Similarly, a second signal is produced by adding together recorded signals $g_i(t)$ for $1 < i < m$ after delaying the signals $g_i(t)$ for $2 < i < m$ by a time t_i relative to the signal $g_1(t)$. The first and second signals are then combined in order to produce a signal $u_1{}^*$ representative of an optimum estimation of the upgoing wave component. Signals $u_2{}^*, \ldots, u_k{}^*$ are produced in the same manner from set of m recorded signals $\{g_2(t), \ldots, g_{m+1}(t)\}, \ldots, \{g_k(t), \ldots, g_{m+k-1}(t)\}, \ldots$

This method suffers from the drawback of reinforcing, in practice, only those waves which are aligned in the recorded signals after they have been shifted, whereas waves having different velocities simply do not show up.

There also exists the so-called F-K velocity filter method which serves to separate upgoing waves from downgoing waves. Reference can be made to "Vertical Seismic Profiling" by B.A. Hardage, Geophysical Press, 1983, pp. 175-179 for a detailed description of this method.

In this method, the set of signals $g_i(t)$ recorded by the detector at depths z_i for $1 < i < n$ is taken to be a two dimensional signal $g(z, t)$ and the following successive operations are performed :

a) The two-dimensional Fourier transform $G(k, w)$ of the signal $g(z, t)$ is calculated where k and w are the dual variables of z and t respectively in the Fourier transform ; the signal $G(k, w)$ has the advantage that the upgoing waves are to be found in the quadrant $k > 0$, $w > 0$ and the downgoing waves are in the quadrant $k < 0$, $w > 0$;

b) The coefficients contained in the quadrant $k < 0$, $w > 0$ are set to zero or are multiplied by a small factor, e.g. 10^{-3} ; and

c) The inverse two-dimensional Fourier transform is calculated and in the resulting signal $g_u(z, t)$ the downgoing waves are highly attenuated.

This method suffers from problems due to side-effects because of the sharp cut-off between those coefficients which are modified in operation b) and the other coefficients which are not modified. In particular, this gives rise to artifacts and to spectrum folding during operation c).

Further, the Fourier transform using each of the variables z and t requires a certain number of samples to be available. This is no problem for the variable t since there are generally several thousand points available along the t-axis, given that each signal is recorded over a period of several seconds and that the sampling period is about 1 ms. In contrast, the number of points available along the z-axis depends on the number of levels at which signals are recorded, and this is much less.

In order to perform the Fourier transform on the variable z, it is necessary to have at least 64 different recording levels, with the gap between consecutive levels being no greater than a value related to the highest frequency in the received signal and to the lowest propagation velocity, with a typical value being about 10 meters (m). Such a procedure is too expensive.

Another known velocity filter is known as the Tau-P method. This method is equivalent to the F-K method but has the advantage of being suitable for implementation with a smaller number of signals, thereby reducing

measurement costs. However, this method suffers from the same defects of artifacts end spectrum folding as the F-K method.

The aim of the invention is to eliminete the defects of artifacts and of spectrum folding which epeer, in particular, in the above-mentioned prior methods. The invention also seeks to meke it possible to perform velocity filtering on a small number of recorded signals in order to reduce the cost of on-site measuring and to simplify the processing performed on the signals.

More precisely, the present invention provides a method of seismic exploration by filtering e two-dimensional signal $g(z, t)$ built up from e set of signals $g_i(t)$ for $1 < i < n$ as produced by et least one seismic weve detector pleced et different depths $z_1, ..., z_i, ..., z_n$ in a borehole, each of said signels being produced in response to seismic waves being emitted, end said signals including upgoing wave components and downgoing wave components, said filtering consisting in separating said components and the method being characterized in that the operator A is applied to the two-dimensional signal $g(z, t)$, where :

$$A = 1/2\,[Id + \varepsilon.B.H_t.D_z]$$

in which :

Id is the identity operator ;

B is a normalization factor whose value depends on the signal to which the operator A is applied ;

H_t is the one-dimensional Hilbert operator with respect to the variable $\underline{t}$;

D is a differentiation operator with respect to the veriable z ; and

ε is an integer equal to + 1 or − 1 ;

said operator being applied recursively to said two-dimensional signal $g(z, t)$, with tha resulting signal being predominantly constituted by upgoing waves when $\varepsilon = + 1$ and by downgoing weves when $\varepsilon = - 1$.

The normelizetion factor B may be defined, for e function $\underline{g}$, as follows :

$$\sqrt{||H_t.D_z(g)||\ .B} = \sqrt{||g||}$$

where || || indicates the L2 norm of the function.

It will thus be understood that when the operator A is epplied recursivaly to a signal, tha normalization factor B must be recalculated for each iteration as a function of the signal to which the operator A ie epplied.

The Hilbert operator H_t may be defined es follows :

$$H_t(g(t)) = FT^{-1}[j.sgn(\omega).FT(g(t))]$$

where :

$g(t)$ is a function of the variable $\underline{t}$;

FT^{-1} is the inverse Fouriar transform ;

$\underline{j}$ is the complex operator such that $j^2 = - 1$;

sgn is the sign function which is equel to + 1 or − 1 or 0 depending on whether a veriable is positive, negative, or zero ;

$\underline{\omega}$ is the duel variable of the variable $\underline{t}$; end

FT represents the Fourier transform.

Thus, the method in accordance with the invention uses the Fourier transform for the verieble $\underline{t}$ for which the number of samples available is commonly several thousand, while the differentiation operator D_z applied to the variable $\underline{z}$ does not require a large number of recordings z_i to be available.

The differentiation operetor D_z applied to a signal $g(z)$ is defined by :

$$D_z[g(z)] = \sum_{m=1}^{1} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

where l is a parameter whose value may for instance be 1 or 2.

The method of the invention can also be used to perform so-called "fan" filtering so as to retain only those waves having velocities lying between two predetermined velocities Vc_1 and Vc_2. This is done as follows : the recorded signals $g_i(t)$, $2 < i < n$ constituting the two-dimensionel signal $g(z, t)$ are shifted in time reletive to one enother so that the components of waves of velocity Vc_1 appear at the seme instant in eech signal ; the shifted two-dimensional signal is then filtered in accordance with the invention and the resulting signal is time shifted to cancel the initial shift. The ssme operation is performed for the two-dimensional signal $g(z, t)$ for the velocity Vc_2 in order to produce a second two-dimensional signal. The difference between the two two-dimensional signals is then taken in order to produce a two-dimensional signal comprising only those waves whose velocities lie between Vc_1 and Vc_2.

The characteristics and advantages of the invention appear more clearly from the following description, given by way of illustrative and non-limiting example and with reference to the accompanying drawings, in which :

Figure 1 is a diegram of an installation for seismic exploration suitable for obtaining a vertical seismic profile ;

Figure 2 shows in highly simplified menner the paths of upgoing and down seismic waves relating to two different positions of the detector ;

Figure 3 shows the positions of the upgoing waves U and the downgoing waves D in the ω-k plot of the F-K transform domain ;

Figure 4 is a diegram of the transfer function of the operator R in the ω-k plot of the F-K transform domain;

Figura 5 is a diegram of the transfer function of the operator A in the ω-k plot of the F-K transform domain;

Figures 6 to 9 ere respectively a signel recorded by means of an installation in accordance with Figura 1; and the upgoing wave signel after one (Figure 7), two (Figure 8) and three (Figure 9) applicatione of the operator A with $l = 1$;

Figures 10 to 12 respectivaly show tha signal recorded by meane of an installation in eccordance with Figure 1, and an upgoing wave signal and a downgoing wave signal obtained in accordance with the invention;

Figure 13 is e flow chert of processing means in an installation for implementing the method in accordancs with the invention ;

Figure 14 is a plot of tha ω-k transform showing the zone containing ell of the weves whose velocitiee lie between the velocities Vc_1 and Vc_2 ; and

Figures 15a to 15e are plots ehowing the filtering of a detected eignal $g(z, t)$ for eliminating wevee having a velocity less then Vc_1 from this signal.

Figure 1 ehows an installation for seismic exploration comprising a drilling derrick 2 dispoead over a borehole 4 drilled in ground formatione 6.

A downhola apparatus 8 including a seismic wave sensor such as a geophone is suepandad down the borahola 4 by maans of an alectric cable 10 which paeses over sheaves mounted on the drilling derrick. Tha cable 10 is used for diaplacing the apparatus 8 within the borehole and simultansouely sarves to transmit the detection signels produced by the sensor towards surface equipment 12. In conventionel manner, the surface equipment 12 comprises a winch for winding the cable and means for determining the depth at which the downhole apperatus 8 is located, together with means for processing and recording the detection signals transmitted via the cabla 10.

The downhole apparatus 6 may be conventionally constituted by a moving anchor member 14 capable of anchoring in the wall in order to ensure appropriete contact between the sensor and the wall of the borehole. This takes place only when the apparatus 8 has arrived et e depth at which a measurement is to be performed, with the surface equipment 12 than transmitting a message in order to cause the element 14 to move into the enchoring position.

A eourca of seismic wavee 16 ie located on the surface at a given dietance from the head of the borehole. This source may be conetituted by any suitable device such as an air gun. The source 16 is controllad from the surfece equipment 12 in order to fire a shot when the downhole apparatus 14 is anchored at one of tha specified depths.

Several shots are generally fired for each depth, and all of the signals produced in this way are stored and added together in the surface equipment 12 so as to obtain a signal for each level in which the significant components ere reinforced to the detriment of random noise components. This signal is referred to below as tha detection signal.

The eet of detaction signals $g_i(t)$ obtained at the varioue levels z_i for $1 < i < n$ is used to produce graphic recordings (known as seismic traces) which are put together in a single document callad the vertical seismic profile.

Figure 2 shows highly simplified versions of the paths of the sound waves detected by the sensor at two

different levals. Reference 18 designates a reflecting horizon or "reflector" which is deeper than the bottom 20 of the borehole. The reflector 18 is constituted by the interface between two layers of significantly different acoustic impadances.

The sensor placed at A_1 at level z_1 receives a sound wave coming directly from the source end called the downgoing wave, and also recaives a wave reflected by the reflector 18, end called the upgoing wave. The upgoing wave needs to be shown up in order to be able to determine the depth of the reflector end also its reflection coefficiant.

Tha detection signal $g_1(t)$ obtained at level z_1 is thus the eum of a downgoing wava component and an upgoing wave component, and in addition it includes noise components, some of which come from multiple reflections on raflectors situated between the surface and the bottom of the borehole.

The sensor placed at A_k at level z_k similarly receivas a downgoing wave and an upgoing wave, however the downgoing wave arrives later and the upgoing wave arrives soonar.

The method of the invention consists in processing the two-dimensional signal g(z, t) in order to isolate either the upgoing waves, or else the downgoing waves.

The invention lias firstly in the definition of two functions g_u and g_d which correspond respectively to the upgoing waves end to the downgoing waves, and secondly in the use of approximate expressions for these functions in order to provide a valocity filter.

We begin by showing the functions :

$$g_u = 1/2\ [g + H2(g)] \text{ and}$$

$$g_d = 1/2\ [g - H2(g)]$$

where H2 is the two-dimensional Hilbert transform respectively containing the upgoing waves end the downgoing waves of the recorded signal g(z, t).

This is achieved by using the known properties of the Fourier transform. It is known that in the F-K transform domain, the upgoing waves lie in the quadrants for which the variables ω and k have opposite signs, wheraas the downgoing waves lie in the quadrants for which tha variables ω and k hava the same sign.

In the Figure 3 plot, the upgoing waves U lie in quadrants II and IV, and the downgoing waves D lie in quadrants I and III.

Using the definitione of the Fourier and of the Hilbert transforms, the following equation can be daduced :

$$FT[H(f)](\omega) = j.sgn(\omega).FT[f](\omega) \quad (1)$$

where :

FT end H are the one-dimensional Fourier and Hilbert transforma, respectively :

f is e function ;

j is the complex oparator such that $j^2 = -1$; and

sgn is the sign function which is defined by

sgn(ω) = + 1 if ω > 0
sgn(ω) = − 1 if ω < 0
sgn(ω) = 0 if ω = 0.

The naxt relationship is easily derived from equation (1) :

$$FT2[H2(g)](\omega, k) = -\ sgn(\omega, k).FT2[g](\omega, k)$$

where FT2 and H2 are tha two-dimensional Fourier and Hilbert transforms respectively.

$FT2[g_u](\omega, k)$ can then be expressed in the following form :

$$FT2[g_u](\omega, k) = 1/2\ (FT2[g](\omega, k) + FT2[H2(g)](\omega, k))$$

whanca :

$$FT2[g_u](\omega,k) = \frac{1 - sgn(\omega,k)}{2} \cdot FT2[g](\omega,k)$$

The coefficiant $(1 - sgn(\omega, k))/2$ is equal to 1 in quadrants II and IV and is equel to 0 in quadrants I and III of the Figure 3 plot, thus showing that the function g_u contains upgoing waves only.

It can similerly be shown that

$$FT2[g_d](\omega,k) = \frac{1 + sgn(\omega,k)}{2} \cdot FT2[g](\omega,k)$$

which meens thet the function g_d is equal to the signal g in quadrants I and III, end is equal to 0 in quadrants II end IV, i.e. that the function g_d contains downgoing waves only.

Velocity filtering in accordance with the invention thus consists in applying the operator R equal to $1/2.[Id + \varepsilon H2]$, to the recorded signal $g(z, t)$, with Id being the identity operator and $\varepsilon = -1$ or $+1$ depending on whether tha upgoing waves or the downgoing waves are to be obtained.

The two-dimensional Hilbert transform H2 comprises a transform H_t with respect to the veriable t and a traneform H_z with reepect to the varieble z. In order to apply these transforme directly, it is necessery for the number of semples in the signal along the variable in question to be large, for example not less then 100.

There is no problem for the H_t transform since several thousand points ere generally available elong the t-axis.

In contrast, tha number of points along the z-axis, i.e. the number of recorded eignale $g_i(t)$ with $1 < i < n$ is limited for reasons of cost. Tha operator H_z cannot therefore be epplied directly.

In accordance with tha invention, tha operator H_z is repleced by a differentiation operator D_z, i.e. an operator operating on e limited number of points along the z-axis and which constitutes an epproximation to the operator H_z, and the operator R modified in this way is epplied recursively.

More precisely, the operator R equel to

$$1/2[Id + \varepsilon H_t H_z]$$

ie repleced by the operator A which is equel to

$$1/2\,[Id + \varepsilon B.H_t.D_z]$$

where B is a normalization coefficient whose value depende on the signal g to which the operator A is applied in such e menner that the norm of the eignal A[g] is equal to the norm of the signal g.

Perticular implementations of tha operators H_t and D_z are now described.

Tha Hilbart transform H_t may be implemented by any of the methods known to the person skilled in tha art. In perticular, the conventionel formulation of the Hilbert transform using a convolution may be used :

$$H_t(g) = g.CONV.(1/t)$$

However, it is preferabla to use the following equation deduced from equation (1) :

$$H_t(g) = IFT_t[j.sign(\omega).FT_t(g)]$$

where IFT_t is the inverse Fourier transform.

In this equation, the Hilbert transform of the function g is obtained by calculating the Fourier transform of the function g, multiplying the result by $j.sgn(\omega)$, end calculating the inverse transform. This method has the advantages of being very fast and of providing a very accurate result. As for the operetor D_z, it is advantageous to use en expression of the following form :

$$D_z[g(z)] = \sum_{m=1}^{l} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

where l is an integer whose value is not more than a few units. For l = 1, D constitutes a three-level filter and for l = 2 it constitutes a seven-level filter.

It has been observed experimentally that filtering is already very effective for l = 1.

In this particular case, the filtering process of the invention may be explained, from a theoretical point of view, as follows.

From equation (1) it can be deduced that the Hilbert transform H_t has j.sgn(ω) as its transfer function. Similarly, H_z has j.sgn(k) as its transfer function. From this it can be deduced that the operator R has a transfer function T(R) equal to :

$$(1 - \mathrm{sgn}(\omega.k))/2.$$

In the operator A, H_z is replaced by D_z. When l = 1, it is shown that D_z has j.sin(k) as its transfer function. The transfer function T(A) of the operator A is thus :

$$T(A) = \frac{1 - \mathrm{sgn}(\omega).\sin(k)}{2}$$

Figures 4 and 5 are diagrams of the transfer functions T(R) and T(A) in the ω-k plot of the F-K transform domain. The coefficients shown in the quadrants are the multiplicative coefficients applied to each signal sample in the quadrant.

In Figure 4, the value of the multiplicative coefficient switches abruptly from one value to another when moving from one of the quadrants into an adjacent quadrant. As mentioned above, this gives rise to defects in the filtered signal, and in particular it gives rise to spectrum folding.

In contrast, it can be seen that the value of the multiplicative coefficients shown in Figure 5 changes continuously on moving from one quadrant to another. This explains why a signal filtered in accordance with the method of the present invention does not suffer from spectrum folding.

It is also recalled that in accordance with the invention the operator A is applied recursively to the recorded signal g(z, t). Thus, in fact, it is the operator A^p for integer p that is applied, and the multiplicative coefficients are the coefficients shown in Figure 5 raised to the power p. It is clear that A^p gets closer to R for increasing p.

It has been observed experimentally that, for upgoing waves, the filtered signal is already usable with p = 1, and becomes very good with p = 2. As for downgoing waves, the filtered signal is already good with p = 1 since the signal/noise ratio for these waves is higher than for upgoing waves.

When filtering to show up the upgoing waves, it is possible to apply bandpass filtering over the band [2 Hz, 50 Hz] after each application of the operator A in order to remove residual high frequency downgoing waves.

Figure 6 shows a two-dimensional signal g(z, t) recorded by means of an installation such as that shown in Figure 1. The upgoing waves are not apparent in this raw signal.

Figure 7 shows a signal obtained after applying three-level filtering to the Figure 6 signal with an operator A for which ε = + 1 and l = 1. The upgoing waves show up much more clearly, while the downgoing waves are attenuated.

The signal shown in Figure 8 is the result of reapplying the operator A on the Figure 7 signal. The upgoing waves are nearly perfect and the residual downgoing waves can hardly be seen.

Figure 9 shows the result of applying the operator A to the Figure 8 signal. Figure 9 is pratically identical to Figure 8 which means that filtering convergence has already been obtained in Figure 8.

Figure 10 shows another signal recorded by means of an installation such as that shown in Figure 1. This signal has been filtered in accordance with the invention using an operator A for which ε = + 1 and l = 1, and

with an operator A in which $\varepsilon = -1$ and $l = 1$. The corresponding upgoing and downgoing signals are shown respectively in Figures 11 and 12.

Figure 13 is a flow chart applicable to an installation in accordance with the invention for filtering a two-dimensional signal g(z, t).

This installation comprises a memory 22 for receiving the detection signals $g_i(t)$, for $1 < i < n$ constituting the two-dimensional signal g(z, t).

This memory is controlled to provide the necessary signals $g_i(t)$ to calculating means 24 in order to produce the result of applying the operator D_z to the signal g(z, t). E.g., when the operator D_z is defined by $D_z[h(z)] = h(z-1) - h(z+1)$ for some function h, the memory is controlled to provide the calculating means 24 with pairs of values $(g_i(t), g_{i+2}(t))$ for $1 < i < n-2$.

The signal $D_z[g(z, t)]$ delivered by the calculating means 24 is then received by calculating means 26 which produces the Hilbert transform relative to the variable t. This Hilbert transform may be performed in any known manner, and in particular, as mentioned above, it may be performed using the Fourier transform in the following equation :

$$H_t(g) = IFT_t[j.\mathrm{sgn}(\omega).FT_t(g)]$$

The signal $H_t.D_z.[g(z, t)]$ delivered by the calculating means 26 is applied to one of the inputs of calculating means 28 ; the signal contained in the memory 22 is applied to the other input of the calculating means 28. This calculating means 28 calculates the value of the coefficient B which appears in the operator A of methods in accordance with the invention to make the operator A conserve the amplitude of the signal applied thereto.

The coefficient B delivered by the calculating means 28 is then multiplied by the signal delivered by the calculating means 26 in a multiplier 30. The multiplier 30 also receives the coefficient ε whose value is fixed by the user : $\varepsilon = +1$ if the upgoing waves in the signal g(z, t) are to be retained, or else $\varepsilon = -1$ if the downgoing waves are to be retained.

The signal $\varepsilon.B.H_t.D_z.[g(z, t)]$ delivered by the multiplier 30 is received on one of the inputs to an adder 32 whose other input receives the signal contained in the memory 22. The resulting signal is then applied to one of the inputs of a divide-by-two circuit 34.

The means 24 to 34 constitute a particular embodiment for implementing the operator A. In accordence with the invention, this operator is applied recursively. The number of times l that this operator is applied to the two-dimensional signal may be loaded, for example, into a counter 36 which controls a multiplexer 38.

The input of the multiplexer is connected to the output from the divider 34 ; one of its outputs is connected to the memory 40 and its other output is connected to the memory 22. The counter is initially loaded with the value l and is decremented each time the operator A is applied. So long as the contents of the counter is not zero, the divider 34 is connected to the memory 22. When the counter reaches the value 0, the divider 34 is connected to the memory 40.

A recorder 42 is connected to the memory 40 in order to produce a graphical recording of the processed two-dimensional signal as shown in Figures 7, 8, 9, 11, and 12.

Figures 7, 8, 9, and 11 show signals which contain only upgoing wave components. In these signals, all of the upgoing waves are present regardless of their velocities. Similarly, the signal shown in Figure 12 includes all of the downgoing wave components, regardless of their velocities.

It is possible to perform filtering over a fan so as to retain only those waves whose velocities lie in a predetermined velocity band. Such filtering serves to eliminate noise components and components which are not applicable to the intended analysis to be performed on the detected signal g(z, t).

For example, instead of conserving all of the upgoing waves, i.e. all of quadrants II and IV in the Figure 3 plot, it may be desirable to conserve only those waves whose velocities lie in the band $[Vc_1, Vc_2]$, i.e. in the unshaded portion of the plot shown in Figure 14.

Such fan filtering may be obtained in three stages by using the method of separating upgoing and downgoing components in accordance with the invention. The first stage consists in processing the signal g(z, t) to produce a first signal $g_1(z, t)$ from which all waves having a velocity of less than Vc_1 have been eliminated.

Similarly, the second stage consists in processing the signal g(z, t) in order to produce a second signal $g_2(z, t)$ from which all waves having a velocity less than Vc_2 have been eliminated.

Finally, the third stage consists in subtracting the signal $g_2(z, t)$ from the signal $g_1(z, t)$ in order to produce a signal $g_{12}(z, t)$ which contains only those waves whose velocities lie between Vc_1 and Vc_2.

The first stage of such range filtering is described with reference to Figures 15a to 15e. In Figure 15a, three upgoing waves having different velocities Vc_0, Vc_1, and Vc_3 such that $Vc_0 > Vc_1 > Vc_3$ are shown diagrammatically.

To begin with, the signals $g_i(t)$ for $2 < i < n$ constituting the two-dimensional signal g(z, t) are time shifted

such that in each signal $g_i(t)$ for $1 < i < n$ the components of waves at velocity Vc_1 are aligned. As a result the upgoing wave of velocity Vc_0 becomes a downgoing wave (Figure 15b). Such shifting is described in above-mentioned patent document FR-A-2 494 450, but for use in a different application.

The velocity filtering method in accordance with the invention is then applied in order to show up the upgoing wave components in the shifted signal. In the transform domain plot shown in Figure 15c, this gives rise to a high degree of attenuation for the waves contained in quadrants I and III. In the time domain plot of Figure 15d, waves of velocities less than Vc_1 are emphasized whereas waves of velocities greater than Vc_1 are highly attenuated.

The first stage terminates by shifting the signals $g_i(t)$ for $2 < i < n$ back again in order to cancel the time shift performed initially. This gives rise to the signal $g_i(z, t)$ which is shown in the Figure 15e plot.

The second stage is identical to the first stage except that the signals $g_i(t)$ for $2 < i < n$ are time shifted so that wave components of velocity Vc_2 are aligned in the signals $g_i(t)$ for $1 < i < n$.

The time shifts performed at the beginning of the first and second stages are delays when the velocities Vc_1 and Vc_2 are positive (upgoing waves) ; the shifts would be advances if the velocities were negative (downgoing waves).

A signal $g_{12}(z, t)$ which predominantely contains waves whose velocities lie in the band $[Vc_1, Vc_2]$ is obtained merely by taking the difference between the signal $g_1(z, t)$ produced in the first stage and the signal $g_2(z, t)$ produced in the second stage.

Claims

1. A method of seismic exploration by filtering a two-dimensional signal $g(z, t)$ built up from a set of signals $g_i(t)$ for $1 < i < n$ as produced by at least one seismic wave detector placed at different depths $z_1, ..., z_i, ..., z_n$ in a borehole, each of said signals being produced in response to seismic waves being emitted, and said signals including upgoing wave components and downgoing wave components, said filtering consisting in separating said components and the method being characterized in that the operator A is applied to the two-dimensional signal $g(z, t)$, where :

$$A = 1/2\,[Id + \varepsilon.B.H_t.D_z]$$

in which :

Id is the identity operator ;

B is a normalization factor whose value depends on the signal to which the operator A is applied ;

H_t is the one-dimensional Hilbert operator with respect to the variable $\underline{t}$;

D is a differentiation operator with respect to the variable $\underline{z}$; and

ε is an integer equal to + 1 or − 1 ;

said operator being applied recursively to said two-dimensional signal $g(z, t)$, with the resulting signal being predominantly constituted by upgoing waves when $\varepsilon = +1$ and by downgoing waves when $\varepsilon = -1$.

2. A method according to claim 1, characterized in that the operator D_z is defined by :

$$D_z[g(z)] = \sum_{m=1}^{l} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

where $\underline{g}$ is some function and $\underline{l}$ is an integer.

3. A method according to claim 2, characterized in that l is equal to 1.

4. A method according to claim 2, characterized in that l is equal to 2.

5. A method according to any one of claims 1 to 4, characterized in that the operator H_t is defined by :

$$H_t[g(t)] = IFT\,[j.sgn(\omega).FT(g(t))]$$

where :

$\underline{g}$ is some function ;

FT represents the Fourier transform ;

IFT represents the inverse Fourier transform ;

sgn(ω) designates the sign of the variable ω, which is the dual of t ; and

j is the complex operator such that $j^2 = -1$.

6. A method according to any one of claims 1 to 5, characterized in that the operator A is applied once only to the signal g(z, t).

7. A method of velocity filtering a two-dimensional signal g(z, t) built up from a set of signals $g_i(t)$ for 1 < i < n, said signals being produced by sound wave detectors placed at different depths $z_1, ..., z_i, ..., z_n$ down a borehole, each signal being produced in response to sound waves being emitted from a source on the surface, the velocity filtering serving to reinforce waves in the signal g(z, t) having velocities lying between predetermined velocities Vc_1 and Vc_2, said method being characterized in that it comprises the following operations :

A) a) producing a first shifted two-dimensional signal by applying a time ehift to the eignal $g_i(t)$ for 2 < i < n in order to time align the wave components of velocity Vc_1 in the signals $g_i(t)$ for 1 < i < n ;

b) filtering said shifted signal using the method according to any ona of claims 1 to 6 ;

c) producing a first two-dimensional signal $g_1(z, t)$ by time shifting the signals $g_i(t)$ for 2 < i < n of sald filtarad signal in such e manner as to cancel the preceding time shift ;

B) a) producing a second shiftad two-dimensional signal by performing a time shift on the signals $g_i(t)$ for 2 < i < n in order to time align the wave components of velocity Vc_2 in the signels $g_i(t)$ for 1 < i < n ;

b) filtering said shifted signal using the method according to any one of claims 1 to 6 ;

c) producing a second two-dimensional signal $g_2(z, t)$ by time shifting the signals $g_i(t)$ for 2 < i < n of seld filtered signal in order to cancel the preceding time shift ; and

C) taking tha difference between the signals $g_1(z, t)$ and $g_2(z, t)$ in order to produce a signal $g_{12}(z, t)$ which is predominetely constituted by weves having velocities lying between Vc_1 and Vc_2.

8. A seismic exploration inetallation for implementing the method according to cleim 1, the inetalletion comprising at leaet one sound wava detector together with meane for displacing seid detector elong e borehole, meane for recording e two-dimensional signal g(z, t) constituted by the signals $g_i(t)$ for 1 < i < n produced by the detector, seid signals including upgoing wave components and downgoing wave components, and velocity filtering meana for separating said componants, the inatallation being cherecterized in that said velocity filtering meane comprise :

a memory (22) for receiving the two-dimensional signel g(z, t) ;

calculating means (24) for applying the discrete differentiation operator D_z with raepact to the varieble z in the signal contained in the memory (22) ;

calculating meane (26) for applying the Hilbert operator H_t with respect to the variable t to the signel delivered by tha pracading calculating means (24) ;

calculating maans (28) for determining the value of the coefficient B as a function of the signale delivared by the memory (22) and by the preceding calculating meane (26) ;

a multipliar (30) for multiplying together the coefficiant ε, the coefficient B, and tha signel produced by the calculating means (26) ;

an adder (32) receiving the signal contained in tha memory (22) and the signal produced by the multiplier (30) ;

a divide-by-two circuit (34) receiving the signal produced by the addar (32) ;

e multiplexer (38) having one input connected to the output from the divide-by-two circuit (34) and having two outputs, one of which is connected to a memory (40) and the other of which is connected to the calculating means (24) ;

a counter (36) controlling the multiplexer, said counter controlling the number of times the operator A is applied to the signal g(z, t) ;

and recording meane (42) connected to the memory (40).

9. An installation according to claim 8, characterized in that the calculating meens (24) implamants the operator D_z defined by :

$$D_z[g(z)] = \sum_{m=1}^{l} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

where g is some function and l is an integer.

10. An installation according to claim 9, characterized in that l is equal to 1.

11. An installation according to claim 9, characterized in that l is equal to 2.

12. An installation according to any of claims 8 to 11, characterized in that the calculating means (26) implements the operator H_t defined by :

$$H_t[g(t)] = IFT\,[j.sgn(\omega).FT(g(t)]$$

where :

g is some function ;

FT represents the Fourier transform ;

IFT represents the inverse Fourier transform ;

$sgn(\omega)$ designates the sign of the variable ω, which is the dual of t ; and

j is the complex operator such that $j^2 = -1$.

13. An installation according to any one of claims 8 to 12, characterized in that the counter (36) controls the multiplexer (38) so that the operator A is applied only once to the signal g(z, t).

14. An installation according to any one of claims 8 to 13, characterized in that it further includes means for time shifting the signals $g_i(t)$ for $2 < i < n$ constituting the signal g(z, t) stored in the memories (22, 40), together with means for subtracting the signals $g_1(z, t)$ and $g_2(z, t)$ contained in the memory (40) from each other.

Patentansprüche

1. Ein seismisches Explorationsverfahren durch Filtern eines zweidimensionalen Signals g(z, t), aufgebaut aus einem Satz von Signalen $g_i(t)$ for $l < i < n$, wie es erzeugt wird durch mindestens einen seismischen Wellendetektor, der an unterschiedlichen Tiefen $z_1, \ldots, z_i, \ldots, z_n$ in einem Bohrloch plaziert ist, wobei jedes der genannten Signale erzeugt wird im Ansprechen auf ausgesandte seismische Wellen und die Signale aufwärts gehende Wellenkomponenten und abwärts gehende Wellenkomponenten umfassen, wobei das Filtern darin besteht, die Komponenten zu trennen, welches Verfahren dadurch gekennzeichnet ist, daß der Operator A auf das zweidimensionale Signal g(z, t) angewandt wird, worin

$$A = 1/2\,[Id + \varepsilon.B.H_t.D_z]$$

worin

Id der Identitätsoperator ist ;

B ein Normalisierungsfaktor ist, dessen Wert abhängt von dem Signal, auf das der Operator A angewandt wird ;

H_t der eindimensionale Hilbert-Operator bezüglich der Variablen t ist ;

D ein Differenzierungsoperator bezüglich der Variablen z ist ; und

ε eine ganze Zahl gleich + 1 oder – 1 ist ;

welcher Operator rekursiv auf das zweidimensionale Signal g(z, t) angewendt wird, wobei das resultierende Signal überwiegend gebildet wird durch aufwärts gehende Wellen, wenn $\varepsilon = +1$ ist, und durch abwärts gehende Wellen, wenn $\varepsilon = -1$ ist.

2. Ein Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der Operator D_z definiert ist durch

$$D_z[g(z)] = \sum_{m=1}^{l} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

worin g eine Funktion ist und l eine ganze Zahl ist.

3. Ein Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß l gleich 1 ist.

4. Ein Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß 1 gleich 2 ist.

5. Ein Verfahren nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß der Operator H_t definiert ist durch :

$$H_t[g(t)] = IFT\,[j.sgn(\omega).FT(g(t)]$$

worin

g eine Funktion ist ;

FT die Fourier-Transformation repräsentiert ;

IFT die inverse Fourier-Transformation repräsentiert ;

sgn(ω) des Vorzeichen der Variablen ω bezeichnet, wae das Duale von $\underline{t}$ ist ; und

$\underline{j}$ der Komplexoperator ist derart, daß $j^2 = -1$ ist.

6. Ein Verfahren nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß der Operator A nur einmal auf das Signal g(z, t) angewendt wird.

7. Ein Verfahren der Geschwindigkeitsfilterung eines zweidimensionalen Signals g(z, t), eufgebaut aus einem Setz von Signelen $g_i(t)$ für 1 < i < n, welche Signale erzeugt werden durch Schallwellendetektoren, die an unterschiedlichen Tiefen $z_1, ..., z_i, ..., z_n$ im Teufenbereich eines Bohrlochs plaziert sind, wobei jedes Signal erzeugt wird im Ansprechen euf Schallwellen, die von einer an der Erdoberfläche befindlichen Quelle emittiert werden, wobei die Geschwindigkeitsfilterung dazu dient, die Wellen in dem Signal g(z, t) zu verstärken mit Geschwindigkeiten, die zwischen vorbestimmten Geschwindigkeiten Vc_1 und Vc_2 liegen, welches Verfahren dedurch gekennzeichnet ist, daß es die folgenden Schritte umfaßt:

A) e) Erzeugen eines ersten verschobenen zweidimensionalen Signals durch Anwenden einer Zeitverschiebung auf das Signal $g_i(t)$ für 2 < i < n zwecks zeitlicher Ausfluchtung der Wellenkomponenten der Geschwindigkeit Vc_1 in den Signalen $g_i(t)$ für 1 < i < n ;

b) Filtern der verschobenen Signale unter Verwendung des Verfahrens nach einem der Ansprüche 1 bis 6 ;

c) Erzeugen eines ersten zweidimensionalen Signals $g(_1z, t)$ durch Zeitverschiebung der Signale $g_i(t)$ für 2 < i < n des gefilterten Signals derart, deß die vorhergehende Zeitverschiebung ausgelöscht wird ;

B) e) Erzeugen eines zweiten verschobenen zweidimensionalen Signels durch Ausführen einer Zeitverschiebung euf die Signale $g_i(t)$ für 2 < i < n zwecks zeitlicher Ausfluchtung der Wellenkomponenten der Geschwindigkeit Vc_2 in den Signalen $g_i(t)$ für 1 < i < n ;

b) Filtern des verschobenen Signals unter Verwendung des Verfahrens nach einem der Ansprüche 1 bis 6 ;

c) Erzeugen eines zweiten zweidimensionelen Signals $g_2(z, t)$ durch Zeitverschiebung der Signele $g_i(t)$ für 2 < i < n des gefilterten Signals zwecks Auslöschung der vorhergehenden Zeitverschiebung, und

C) Verwenden der Differenz zwischen den Signalen $g_1(z,t)$ und $g_2(z, t)$ zwecks Erzeugung eines Signals $g_{12}(z, t)$, des überwiegend von Wellen gebildet wird mit Geschwindigkeiten, die zwischen Vc_1 und Vc_2 liegen.

6. Seismische Exploretionsanlage für die Durchführung des Verfahrens nech Anspruch 1, welche Anlage mindestens einen Schellwellendetektor mit Mitteln für die Verlegerung des Detektors längs eines Bohrloches umfaßt, Mittel für das Aufzeichnen eines zweidimensionalen Signale g(z, t) umfaßt, gebildet durch die Signele $g_i(t)$ für 1 < i < n, erzeugt von dem Detektor, welche Signale aufwärts gehende Wellenkomponenten und ebwärts gehende Wellenkomponenten umfassen, und Geschwindigkeitsfiltermittel für des Trennen der genennten Komponenten, welche Anlage dadurch gekennzeichnet ist, daß die Geschwindigkeitsfiltermittel umfessen :

einen Speicher (22) für den Empfang des zweidimensionalen Signals g(z, t) ;

Berechnungsmittel (24) für die Anwendung des diskreten Differenzierungsoperators D_z bezüglich der Variablen $\underline{z}$ in dem in dem Speicher (22) enthaltenen Signal ;

Berechnungsmittel (26) für das Anwenden des Hilbert-Operators H_t bezüglich der Veriablen $\underline{t}$ euf des Signal, geliefert von den vorhergehenden Berechnungsmitteln (24) ;

Berechnungsmittel (26) für die Bestimmung des Wertes des Koeffizienten B sls Funktion der Signale, geliefert von dem Speicher (22) und von dem vorhergehenden Berechnungsmittel (26) ;

eine Multipliziereinrichtung (30) für das Multiplizieren des Koeffizienten $\underline{s}$ des Koeffizienten B und des Signals, erzeugt durch die Berechnungsmittel (26) ;

eine Addiereinrichtung (32), die das in dem Speicher (22) entheltene Signel und das von der Multipliziereinrichtung (30) erzeugte Signal empfängt ;

einen durch zwei teilenden Scheltkreis (34), der das von der Addiereinrichtung (32) erzeugte Signel empfängt ;

einen Multiplexer (38), der mit einem Eingang an den Ausgang des durch zwei dividierenden Schaltkreises (34) engeschlossen ist, und zwei Ausgänge aufweist, von denen der eine en einen Speicher (40) engeschlossen ist und der andere en die Berechnungsmittel (24) ;

einen Zähler (36), der den Multiplexer steuert und die Anzahl von Melen steuert, wie oft der Operator A euf das Signel g(z, t) angewandt wird ; und

Aufzeichnungsmittel (42), die an den Speicher (40) angeschlossen sind.

9. Eine Anlage nach Anspruch 8, dadurch gekennzeichnet, daß die Berechnungsmittel (24) den Operator D_z implementieren, definiert durch :

$$D_z[g(z)] = \sum_{m=1}^{l} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

worin g eine Funktion und l eine ganze Zahl ist.

10. Eine Anlage nach Anspruch 9, dadurch gekennzeichnet, daß l gleich 1 ist.

11. Eine Anlage nach Anspruch 9, dadurch gekennzeichnet, daß l gleich 2 ist.

12. Eine Anlage nach einem der Ansprüche 8 bis 11, dadurch gekennzeichnet, daß die Berechnungsmittel (26) den Operator H_t implementieren, definiert durch :

$$H_t[g(t)] = IFT\,[j.sgn(\omega).FT(g(t)]$$

worin

g eine Funktion ist ;

FT die Fourier-Transformation repräsentiert ;

IFT die inverse Fourier-Transformation repräsentiert ;

sgn(ω) das Vorzeichen der Variablen ω bezeichnet, die das Duel von t ist ; und

j der Komplexoperator ist derart, daß $j^2 = -1$.

13. Eine Anlage nach einem der Ansprüche 8 bis 12, dadurch gekennzeichnet, daß der Zähler (36) den Multiplexer (38) derart steuert, daß der Operator A nur einmal auf das Signal g(z, t) angewandt wird.

14. Eine Anlage nach einem der Ansprüche 8 bis 13, dadurch gekennzeichnet, daß sie ferner Mittel umfaßt für die Zeitverschiebung der Signel $g_i(t)$ für $2 < i < n$, welche das Signal g(z, t), abgespeichert in den Speichern (22, 40), bildet, zusammen mit Mitteln für das Subtrahieren der Signale $g_1(z, t)$ und $g_2(z, t)$, enthalten im Speicher (40) voneinander.

Revendications

1. Procédé d'exploration sismique dans lequel on filtre un signal bidimensionnel g(z, t) composé d'un ensemble de signaux $g_i(t)$ où $1 < i < n$, produits par au moins un détecteur d'ondes sismiques placé à différentes profondeurs $z_1, \ldots z_i, \ldots z_n$ dans un puits, chaque signal étant produit en réponse à une émission d'ondes sismiques, lesdits signaux comprenent des composantes d'onde de remontante et des composantes d'onde descendente, ledit filtrage consistant à separer lesdites composantes et étant caractérisé en ce qu'on applique au signal bidimensionnel g(z, t) l'operateur A défini par :

$$A = 1/2\,[Id + \varepsilon.B.H_t.D_z]$$

où

— Id est l'opérateur identité,

— B est un facteur de normalisation, dont la valeur dépend du signal auquel l'opérateur A est appliqué,

— H_t est l'opérateur de Hilbert unidimensionnel relatif à la variable t,

— D est un opérateur de différentiation relatif à la variable, z, et

— ε est un entier égal à + 1 ou − 1,

ledit opérateur étant appliqué de manière récursive audit signal bidimensionnel g(z, t), le signal résultant comprenant de façon prédominente les ondes remontantes lorsque ε = + 1, et les ondes descendantes lorsque ε = − 1.

2. Procédé selon la revendication 1, caractérisé en ce que l'opérateur D_z est défini par :

$$D_z\,(g(z))=\sum_{m=1}^{l}\frac{g(z+2m-1)-g(z-2m+1)}{2m-1}$$

où g est une fonction quelconque et l est un nombre entier.

3. Procédé selon la revendication 2 caractérisé en ce que l est égal à 1.

4. Procédé selon la revendication 2, caractérisé en ce que l est égal à 2.

5. Procédé selon l'une quelconque des revendications 1 à 4, caractérisé en ce que l'opérateur H_t est défini par :

$$H_t[g(t)] = IFT\,[j.sgn(\omega).FT(g(t)]$$

où g est une fonction quelconque
FT représente le transformation de Fourier
IFT représente la transformation de Fourier inverse
sgn(ω) note le signe de la variable ω, duale de t
j est le nombre complexe tel que $j^2 = -1$.

6. Procédé selon l'une quelconque des revendications 1 à 5, caractérisé en ce que l'opérateur A est appliqué une seule fois eu signal g(z, t).

7. Procédé de filtrage de vitesse d'un signal bidimensionnel g(z, t) composé d'un ensemble de signaux $g_i(t)$, où $1 < 1 < n$ produits par détecteurs d'ondes acoustiques placés à différentes profondeurs $z_1, ..., z_i, ..., z_n$ dans un puits, chaque signal étant produit an réponse à une émission d'ondes acoustiques à partir d'une source an surface, pour renforcar les ondes du signal g(z, t) ayant una vitesse comprise entre des vitessss prédéterminées Vc_1 at Vc_2, ledit procédé étant caractérisé en ce qu il comprend les opérations suivantes :

A)a) produire un premier signal bidimensionnel décalé en effectuant un décalege temporel des signaux $g_i(t)$, $2 < l < n$, pour aligner temporellement dans les signaux $g_i(t)$, $1 < l < n$, les composentes des ondes de vitesse Vc_1,

b) filtrer ledit signel décalé selon le procédé conforme à l'une quelconque des revendicetions 1 à 6,

c) produire un premier signal bidimensionnel $g_1(z, t)$ en effectuent un décalege temporel des signeux $g_i(t)$, $2 < l < n$, dudit signal filtré, pour annuler le décalage temporel précédent,

B)a) produire un second signal bidimensionnel décalé en effectuant un décalage temporel des signaux $g_i(t)$, $2 < i < n$, pour aligner temporellement dans les signaux $g_i(t)$, $1 < l < n$, les composentas dse ondes de vitesse Vc_2,

b) filtrer ledit signal décalé selon le procédé conforme à l'une quelconque des revendicetions 1 à 6,

c) produire un second signal bidimensionnel $g_2(z, t)$ en effectuant un décalege temporel des signeux $g_i(t)$, $2 < l < n$, dudit signel filtré, pour annuler le décalage temporel précédent,

C) faire la différence des signaux $g_1(z, t)$ at $g_2(z, t)$ pour produire un signal $g_{12}(z, t)$ comprenant de feçon prédominanta les ondes ayant une vitesse comprise entre Vc_1 et Vc_2.

8. Installation d'exploration sismique pour la mise en oeuvre du procédé selon la revendication 1, comprenant au moins un détecteur d'ondes acoustiques et des moyens pour déplacer ce détecteur dans un puits, des moyens pour enregistrer un signal bidimensionnel g(z, t) constitué par les signaux $g_i(t)$, $1 < l < n$, produits par le détecteur, lesdits signaux comprenant des composantes d'onde descendante et des composantes d'onde remontante, et des moyens de filtrage en vitesse pour séparer lesdites composantes, caractérisé en ce que lesdits moyens de filtrage comprennent :

— une mémoire (22) pour recevoir le signal bidimensionnel g(z, t),
— un moyen de calcul (24) pour appliquer l'opérateur D_z de différentietion discret reletivement à la variable z au signel contenu dans la mémoire (22),
— un moyen de calcul (26) pour appliquer l'opérateur H_t de Hilbert relativement à le variable t eu signal délivré par le moyen de calcul (24) précédent,
— un moyen de calcul (28) pour déterminer la valeur du coefficient B en fonction des signaux délivrés par la mémoire (22) et par le moyen de calcul (26) précédent,
— un multiplieur (30) pour multiplier entre eux le coefficient ε, le coefficient B et le signal produit per le moyen de calcul (26),
— un additionneur (32) recevant le signal contenu dans la mémoire (22) et le signal produit par le multiplieur (30),
— un diviseur par deux (34) recevant le signal produit par l'edditionneur (32),
— un multiplieur (38) à une entrée, reliée à la sortie du diviseur par deux (34), st deux sorties, l'une reliée

à une mémoire (40) et l'autre au moyen de calcul (24),

— un compteur (36) commandant le multiplexeur, ledit compteur contrôlant le nombre de fois où l'opérateur A est appliqué au signal g(z, t),

— un moyen d'enregistrement (42) relié à la mémoire (40).

9. Installation selon la revendication 8, caractérisée en ce que le moyen de calcul (24) met en oeuvre l'opérateur D_z défini par :

$$D_z\left[g(z)\right] = \sum_{m=1}^{l} \frac{g(z+2m-1) - g(z-2m+1)}{2m-1}$$

où g est une fonction quelconque et l est un nombre entier.

10. Installation selon la revendication 9, caractérisée en ce que l est égal à 1.

11. Installation selon la revendication 9, caractérisée en ce que l est égal à 2.

12. Installation selon l'une quelconque des revendications 8 à 11, caractérisée en ce que le moyen de calcul (26) met en oeuvre l'opérateur H_t défini par :

$$H_t[g(t)] = IFT\,[j.sgn(\omega).FT(g(t)]$$

où

g est une fonction quelconque

FT représante la transformation de Fourier

IFT représente la transformation de Fourier invarse

sgn(ω) note le signe da la variable ω, duale de t

j est le nombre complexe tel que $j^2 = -1$

13. Installation selon l'une quelconque des revendications 8 a 12, caractérisée en ca que le compteur (36) commande le multiplexeur (38) pour qua l'opérateur A ne soit appliqué qu'una seule fois au signal g(z, t).

14. Installation selon l'une quelconque des revendications 8 à 13 caractérisée an ca qu'elle comprand en outre des moyens pour décaler temporellement les signaux $g_i(t)$, 2 < i < n, constituant la signal g(z, t) mémorisé dans les mémoires (22, 40) et des moyens pour soustraire entre eux des signaux $g_1(z, t)$, $g_2(z, t)$ contenus dans la mémoire (40).

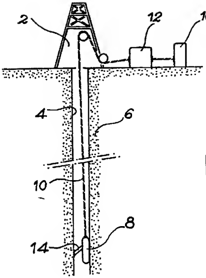


FIG. 1

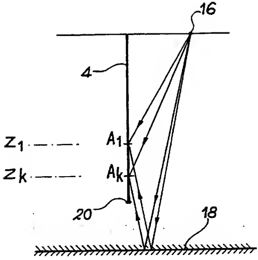


FIG. 2

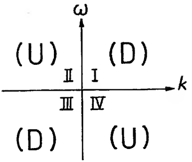


FIG. 3

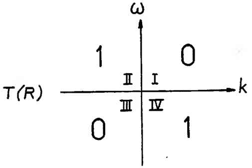
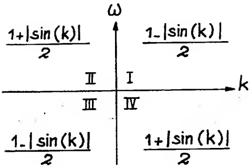


FIG. 4

FIG. 5



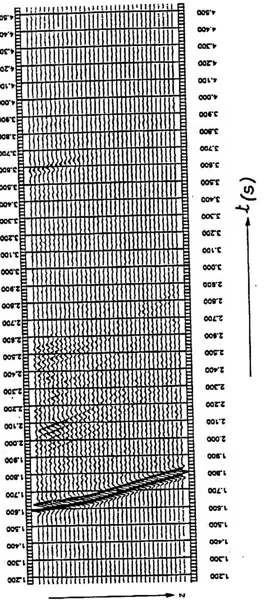


FIG. 6

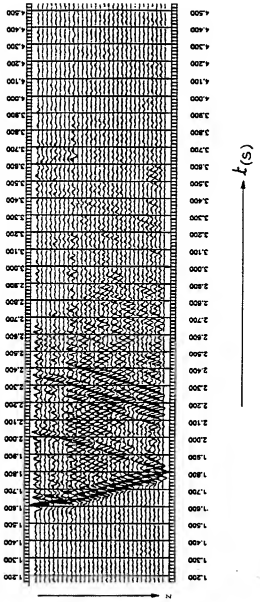

1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
2.300
2.400
2.500
2.600
2.700
2.800
2.900
3.000
3.100
3.200
3.300
3.400
3.500
3.600
3.700
3.800
3.900
4.000
4.100
4.200
4.300
4.400
4.500
z
t(s)

FIG. 7

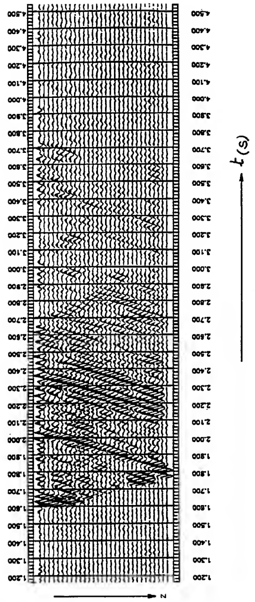

1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
2.300
2.400
2.500
2.600
2.700
2.800
2.900
3.000
3.100
3.200
3.300
3.400
3.500
3.600
3.700
3.800
3.900
4.000
4.100
4.200
4.300
4.400
4.500
N
t(s)

FIG. 8

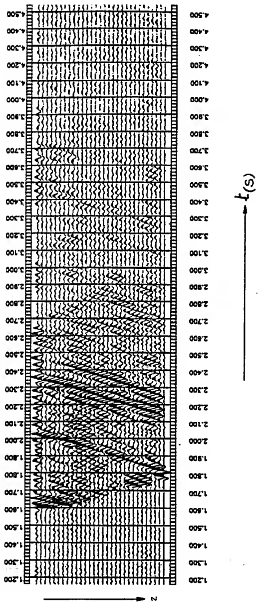


FIG.9

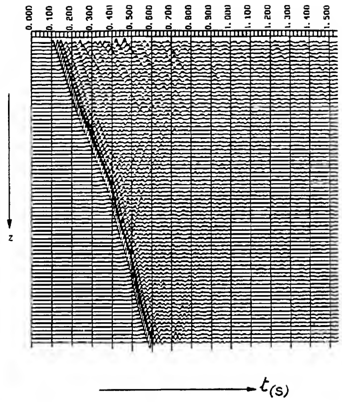

0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
z
t(s)

FIG. 10

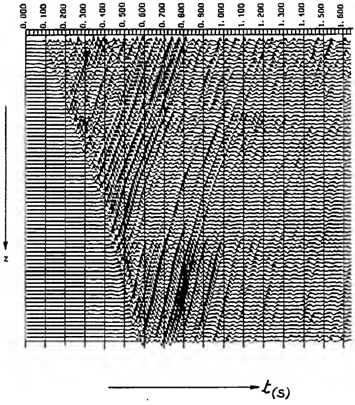

0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
z
$t_{(s)}$

FIG. 11

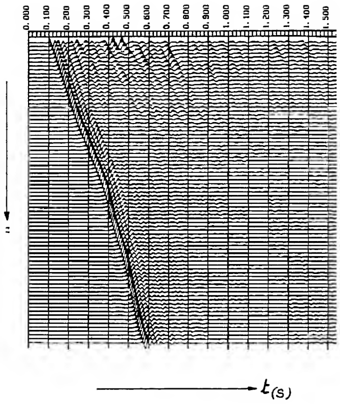

0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
n
t(s)

FIG. 12

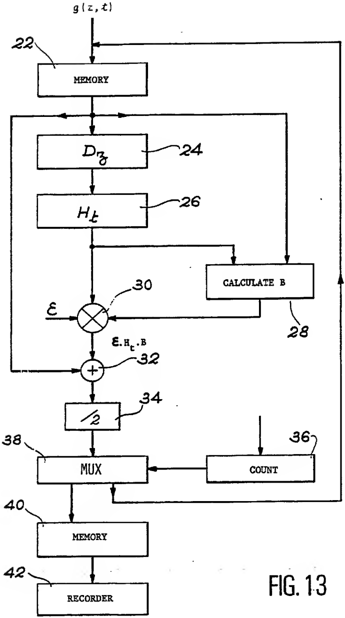

g(z, t)
22
MEMORY
D_z
24
H_t
26
CALCULATE B
30
ε
28
$\varepsilon.H_t.B$
32
34
/2
38
36
MUX
COUNT
40
MEMORY
42
RECORDER

FIG. 13

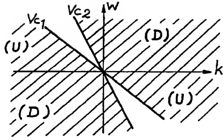


FIG. 14

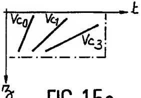


FIG. 15a

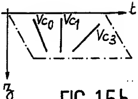


FIG. 15b

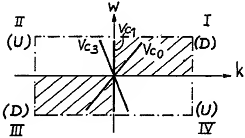


FIG. 15c

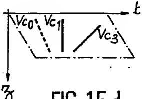


FIG. 15d

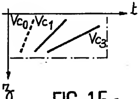


FIG. 15e